reviewed paper

Study on Evaluation of Thermal Environment Following Alleviation of Limit on Number of Floors of Apartment Complex

Ji-Won Ryu, Eung-Ho Jung, Dae-Wuk Kim, Jae-Gyu Cha, Akira Hoyano

(Ph.D. Ji-Won Ryu, Tokyo Institute of Technology, 4259 Nagatsuta-cho, Yokohama, jiwon97@paran.com)
(Prof. Dr.-Ing. Eung-Ho Jung, Keimyung University, Shindang-Dong 1000 Daegu, turep21@kmu.ac.kr)
(Dr.-Ing. Dae-Wuk Kim, Keimyung University, Shindang-Dong 1000 Daegu, dwkim@kmu.ac.kr)
(Ph.D. Jae-Gyu Cha, Keimyung University, Shindang-Dong 1000 Daegu, top4mir@paran.com)
(Prof. Ph.D. Akira Hoyano, Tokyo Institutu of Technology, 4259 Nagatsuta-cho, Yokohama, hoyano@hy.depe.titech.ac.jp)

1 ABSTRACT

To improve the thermal environment in the urban area, improvement of the thermal environment in the built-up area, which takes the most part of the residential area, is necessary. In this study, by using the ThermoRender, the urban heat environment program, qualitatively evaluates the affects of the thermal environment in the apartment complex, according to the alleviation of limit on the number of floors of the apartment complex, and the results are as follow.

First of all, the result shows that the distribution of the surface temperature of the high floors of the apartment complex was lower than that of the lower floors apartment complex, although it shows some variations according to the surface materials and the hours.

Next, MRT(Mean Radiant Temperature), the indicator of the thermal comfort, is the omnidirectionally averaged to the temperature of the affects of decreasing sensory temperature of the heat radiation from 1.5 meters above, and indicates that there is not much difference in the distribution of the temperature between the floors.

Lastly, the HIP analyze shows that there was some difference in the temperature distribution depending on the surface materials, however all showed similar tendency that the temperature rises after the sunrise, falls after 1 p.m, and rises again after sunset.

2 BACKGROUND AND OBJECTIVE OF THE ANALYSIS

As the global environmental problems have become more serious, the heat island effect occurs as an urban heat environmental problem. The heat island effect observed especially during summer seasons, a climatic characteristic which is given by the developed urbanization and high degree of land use, is caused by land cover, waste heat discharged from cars and plants, and ill-ventilated cities. This is the consequence of the interaction of the factors such as weather conditions and air pollution, and the land cover change based on the changed land use within the build-up area is considered as the most significant cause.

On the other hand, the national urbanization rate is more than 90.8% and the apartment buildings, the urban residents' typical building type, started to be constructed from 1970's and became the most common housing type. Especially, the type of the recently constructed apartment house focuses on the high-rise apartment building, which is more likely to occur for the residential environment improvement in the urban cities.

The objective of this analysis is to quantitatively evaluate the influence of apartment house buildings floor number deregulation in the semi-residential area on the apartment complex‘s heat environment, concentrating on the changed land cover within general residential zone and the fact the residential environment improvement focuses on the high-rise apartment buildings, which are the main causes of the urban heat island effect. The results of this study will be used as preliminary data at this point when there is no clear standard of sub-type classification of general residential zone, and also as the data to support the design plan of the green method which considers the heat environment from an urban climate perspective for the future plan of apartment complex.

3 ANALYSIS METHODS

3.1 Program Overview

Until now, thermal environment related researches have been focused on thermal environment in which urban surface temperature were analyzed using the images of metro-scale cities or urban spaces taken by satellites and aircrafts, in connection with GIS. In recent days, thermal environment researches on apartment house buildings have been done actively (Fig. 1).

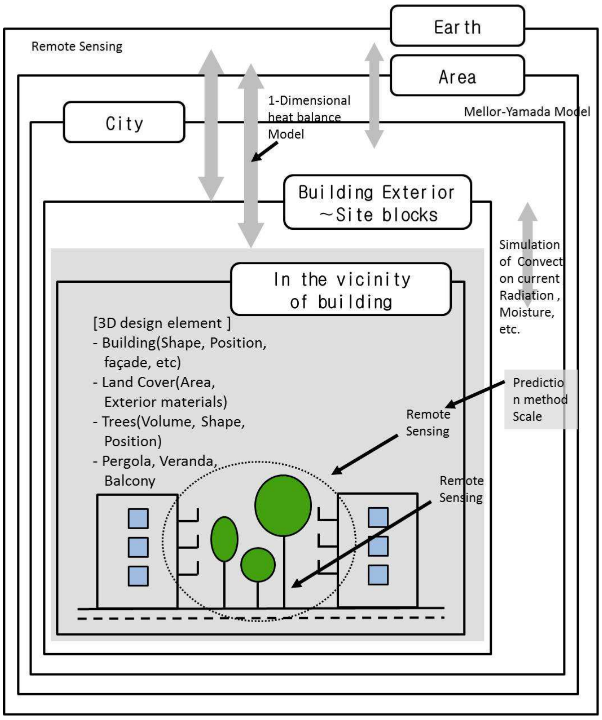


Figure 4: Spatial scale of prediction evaluation method

However, in order to explain the changes of land covers and the increase of artificial array which have become the main factors of recent urban thermal environment, it is necessary to incorporate the effects of construction components, such as buildings' shapes and curves, on buildings' conductivity and urban thermal environment into thermal environment research. In particular, since in a real urban space, the surface temperature of the factors that determine the space such as building and ground is closely connected with the space design including the shape of outdoor space and materials, it is important to set the surface temperature as an indicator in order to realize outdoor space design considering the heat environment.

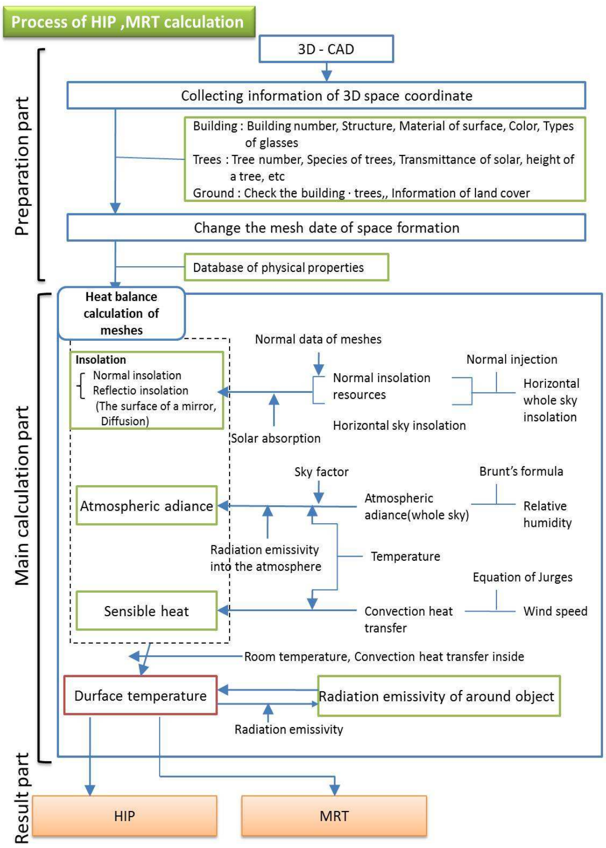


Figure 2: ThermoRender analysis process flow

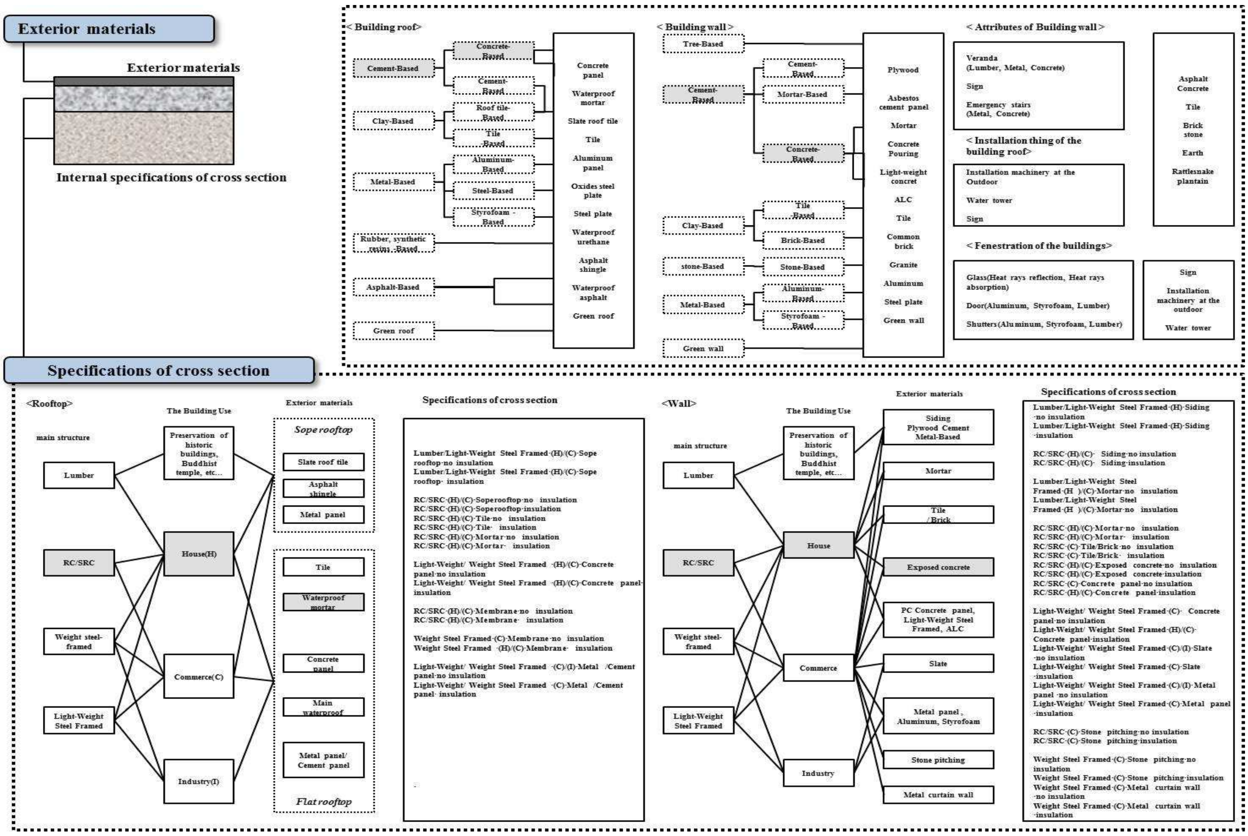


Figure 3: Exterior materials & Specifications of cross sections flow

Accordingly, this evaluates all-surface-temperature of 3-dimension, MRT (Mean Radiant Temperature) and HIP (Heat Island potential) using ThermoRender, the 3D-CAD heat environment simulation which can reproduce cities or architecture scale. ThermoRender of this analysis, based on the relations between land cover, structures and urban heat environment, evaluates the influence of the difference of building shape or materials on the urban heat environment. To simulate them, the program of this analysis focuses on that the heat environment significantly varies with delicate difference of the space design such as various materials, trees or owning. Besides, the program can freely construct materials other than the thermal properties data of more than 100 kinds such as building or ground, and make a new material.

3.2 ThermoRender Analysis Process

ThermoRender inputs and outputs data from 'VectorWorks', the universal 3D-CAD program, and the simulation analysis process consists of three parts; preparation part, main calculation part and result stage(Fig. 2).

3.2.1 Preparation part

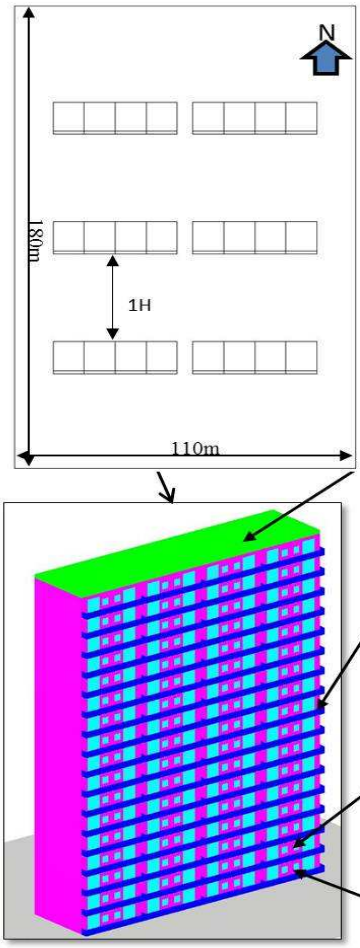
Draws up the target furniture model in 3D-CAD. The section specification and the thermal properties information of each construction materials along with the shapes of building, ground and trees are input(Fig. 3), and constructs the 0.2mass points into a fixed size after finishing the draw-up.

3.2.2 Main calculation part

Calculates the time series surface temperature by calculating the heat balances (direct solar radiation, diffuse sky radiation, reflected radiation, atmospheric radiation, acceptance of long-wave radiation of surrounding features, convective heat transfer, evaporation) at each mass point of the drawn-up furniture model, and using the 1-dimensional unsteady state heat conduction to the section.

3.2.3 Result stage

Displays the results of 3D-CAD calculation and calculates MRT(Mean Radiant Temperature) and HIP (Heat Island Potential) of the furniture, from the all-surface-temperature of 3-dimension.



- **Site scale : A=110m x 180m(19,800㎡)**
- **Building scale and disposition : Flat type(southern aspect), Row houses below the 4 (net area is more than 85㎡)**
- **Floor number : 7F, 12F, 18F**
- **Pavement and material : Asphalt, Glass, Green roof, Wall roof**
- **Threshold density : Building coverage ratio = 60%, Floor area ratio = 220%**
- **Building height : 2.9m**
- **Pitch of building : H × 1m**

Part	Exterior materials		Compositon of materials	Thickness [㎜]	Insolation reflectance (spread) [%]	Radiation emissivity [%]	Specific heat of capacity [KJ/㎡K]	Heat conductivity [W/mK]
Roof	Concrete		Concrete	180	0.3	0.9	1896	1.6
			Condensation guard plate no.2	Side wall: 65 Outer wall 65			25	0.034
			Gypsum Board	9.5			904	0.22
Wall	Concrete		Concrete overlay	50	0.3	0.9	1896	1.6
			Condensation guard plate no.2	110			25	0.034
			Exposed concrete	30			1896	1.6
			Concrete	135			1896	1.6
			Gypsum Board	9.5			904	0.22
Balcony	Fllor	Con-Crete	Concrete	150	0.6	0.8	1900	1.6
			Air layer	100			1.3	0.09
			Concrete	180			1900	1.6
	Railing	Alu-minum	Aluminum	3			3800	53
Window	Double glass		Glass	3	0.08 (mirror plane)	0.94	1900	1
			Air layer	6			1.3	0.12
			Glass	3			1900	1

Figure 4: Site size, type & material attribute

4 ASSUMPTION AND HEAT ENVIRONMENT ANALYSIS

4.1 Assumption

The site scale and types to evaluate the influence of apartment house buildings' floor number deregulation on the heat environment of apartment complex are as followings; The site area is 19,800□ of grid-pattern and the dwelling unit scale and array is south facing considering lamina type and the right-to-have-sunlight, and the block length of the apartment house is less than 4 households (net area is more than 85□).

The buildings include less than 7 stories (highest altitude zone of type-2 general residential zone), less than 12 stories (the standard of type-2 general residential zone is applied) and less than 18 stories (the maximum scope of floor area rate of type-2 general residential zone is applied), and the constant stories are applied for the building block layout.

Asphalt and grass were applied to the ground's surface to analyze the difference of heat environment distribution patterns by floors. The standards of sub-type classification was applied to critical density. Therefore, as the selected area was type-2 general residential zone, the building-to-land ratio of 60% and 220% of floor area rate and floor height of 2.9m were applied.

On the other hand, the material properties to analyze the heat environment of the target site are set based on data from the advance researches as shown in (Fig. 4), and Daegu (37°34″ N latitude and 127°58″ E longitude) is chosen as a standard at August 19th, 2009, the most hot day of the summer seasons. Besides, the room temperature is set to 26℃at average, typical meteorological data for Daegu (temperature for 24 hrs, humidity, direct normal isolation, horizontal diffuse sky radiation, night radiance, wind direction and wind speed) is used for the outdoor condition under assumption that the wind speed is constant at 2.1m/s from the southeast.

4.2 Heat Environment Analysis based on the floor number deregulation

4.2.1 Surface Temperature Profile

When the ground surface is paved with asphalt, the heat environment surface temperature at each floor level of the complex (Fig. 5) shows 32□33℃ at 9 o'clock and the temperature of roof surface was 2□3℃ higher than that of ground. The temperature of shadow region created by the structure was 2□3℃ lower than ground surface.

The surface temperature at 12 PM rose more than 40℃ due to the direct influence of sunlight showing 10℃ higher than the shadow area made by building. Roof surface made of concrete showed high temperature of higher than 50℃ due to direct sunlight in all of 7F, 12F and 18F building, while veranda showed lower temperature than other surrounding parts. Such low temperature of veranda is thought to be influenced by the low surface temperature of glass that was cooled by the lowly set indoor cooling condition.

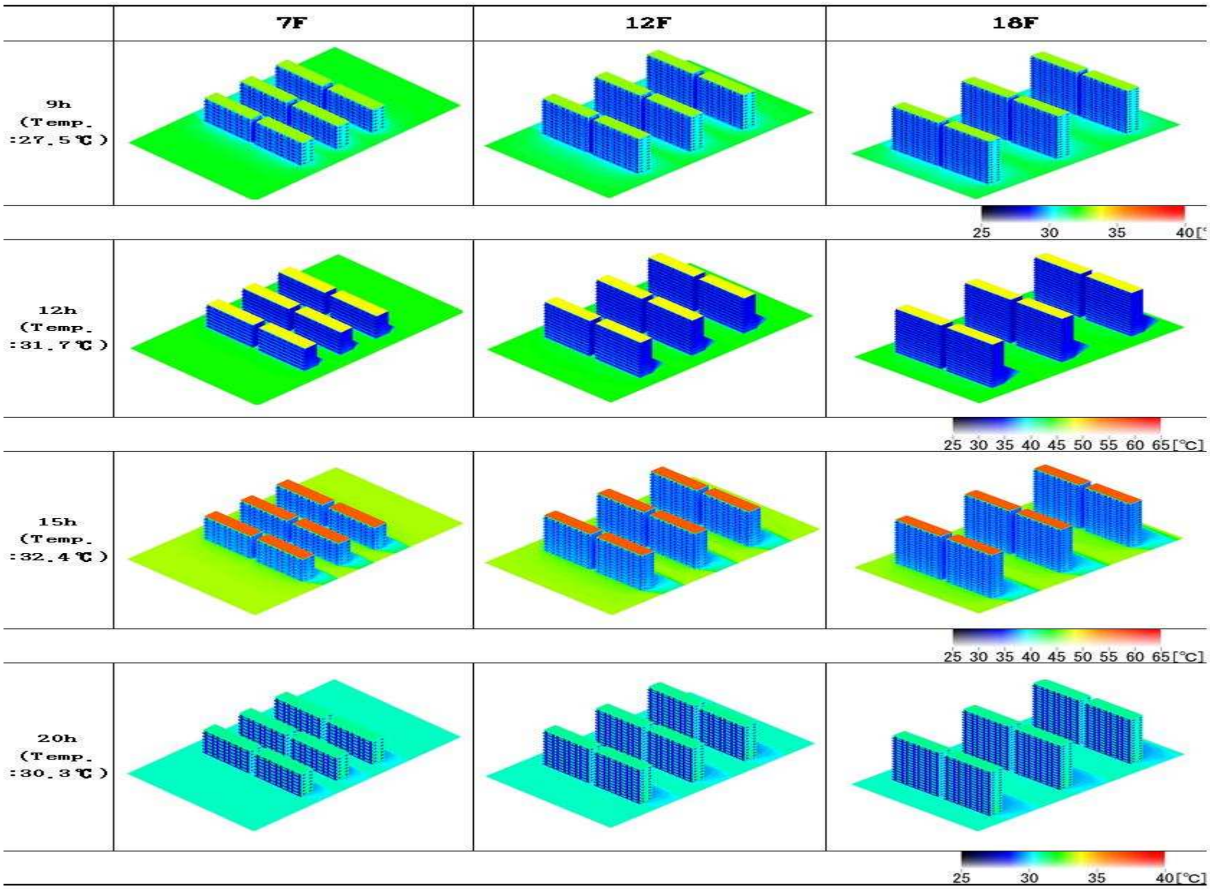


Figure 5: Surface temperature in site(Asphalt)

$$\mathrm{HIP}[^\circ C] = \frac{\int (Ts - Ta)\,dS}{A}$$

Ts□Surface temperature (℃□

Ta□Temperature□℃)

A : projected surface of horizontal plane(□)

S : Area (□)

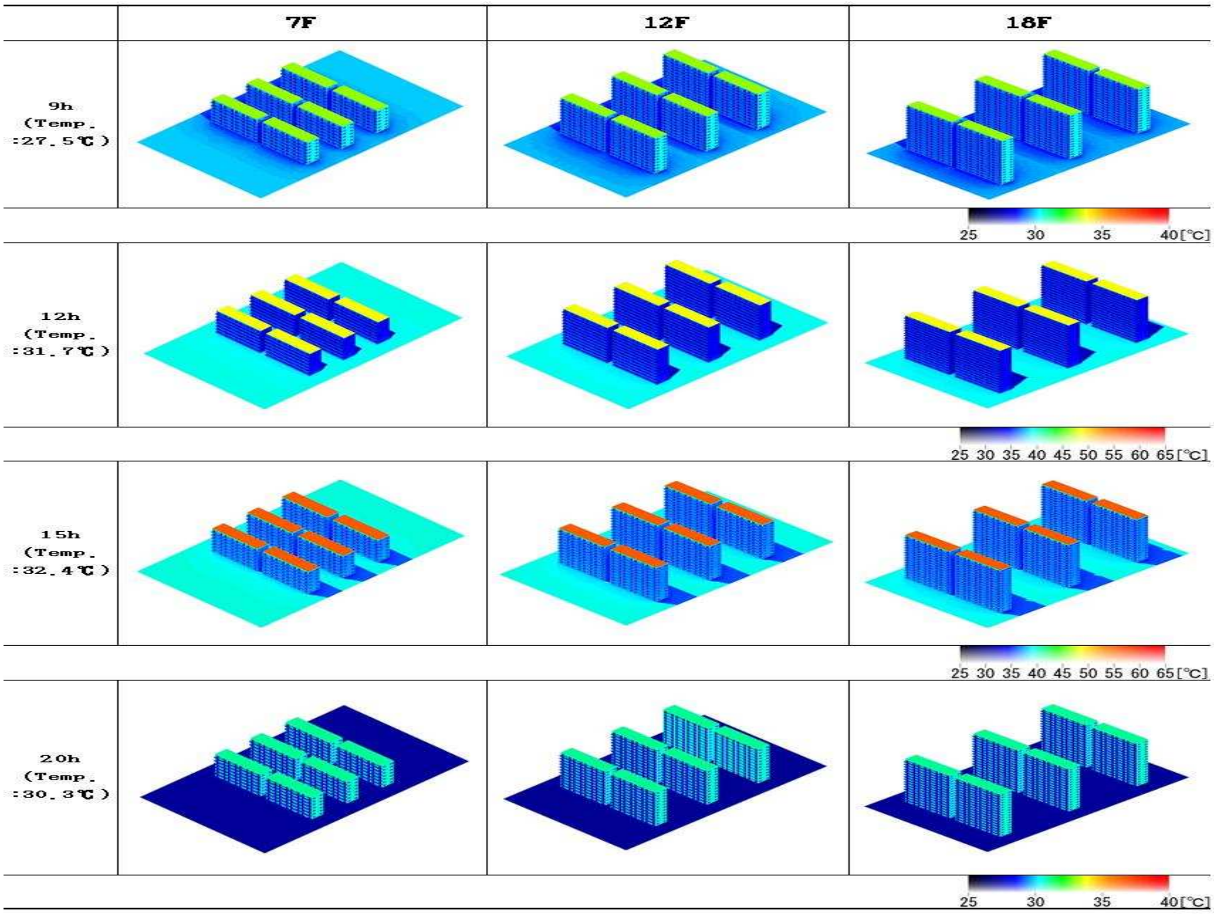


Figure 6: Surface temperature in site(Grass)

At 3 PM, like 12 PM, the surface temperature of roof surface was most high and shadow area was most low from ground surface. At 8 PM, though the sun already set, ground surface temperature showed 30℃ or more in most surfaces other than veranda. In particular, it was found that concrete-made roof showed higher surface temperature than asphalt-made ground surface.

On the other hand, when ground surface is grass (Fig. 6), the temperature of ground surface was low at all the time periods but roof and wall showed similar temperature distribution.

The differences of ground surface temperatures in 7F, 12F and 18F was not significant across times. However, as higher building has the wider area of shadow distribution, it showed lower surface temperature in shadow area. In particular, the temperature distribution of ground surface at 12 PM and 15 PM was lower than that of surrounding sunny spot due to the clear shadow area formed by building.

At 8 PM, far after sunset, the ground surface temperatures in 7F, 12F and 18F was lower than 30.3℃. It seems that such lower temperature than air temperature was resulted by the cooling effect of evaporation and emission of grass and accelerated sky radiation.

4.2.2 HIP Distribution

HIP, which refers the indicator of heat island potential, means the rate of sensible heat generating from all surfaces including building and ground over surface and is a heat indicator that conversed the influence of heat island into the temperature of ground surface. Higher HIP value means the difference between surface temperature and air temperature is big and the influenced sensible heat (the cause of heat island effect) is much.

Figure 7 is the HIP results when asphalt and grass was used for ground surface paving, which showed similar tendency in every time area. It was found that their temperatures started to rise after sunrising and peaked around 1 PM and rose again after 8PM. Regarding to the distribution of floors, at 1PM of most amount of solar radiation, 7F was 14.4℃, 12F was 13.1℃ and 18F was 11.5℃. From 1PM, temperature started to get lower. Higher floors showed higher temperature than lower floors before sunrise and after sunset, while vise versa after sunrise and before sunset.

At 1PM when temperature is most high,   higher floors showed lower temperature than lower floor. It seems that the wide shadow area formed on ground surface kept the surface temperature thereon and accordingly kept low HIP. It seems also that the indoor temperature set at 26℃ kept the surface temperature around veranda low. It could be another reason that the wider veranda of higher floors made lower HIP at higher floors. Higher floors showed higher temperature than lower floors. It can be analyzed that the concrete outer wall of building has low reflexibility, absorbing and storing instead of reflexing, and so could keep high temperature till night.

Figure 8 is the HIP result when grass was applied as ground surface material. Compared with asphalt pavement, HIP value of grass surface was low in overall. The temperature distribution tendency across times in 7F, 12F and 18F was also similar. The HIP value at 1 PM was most high being 9.55℃ in 7F, 8.71℃ in 12F and 7.73℃ in 18F, but about 4~5℃ lower than asphalt pavement.

4.3 Heat Environment Analysis based on Ecological Planting Method

4.3.1 Surface Temperature Profile

In above paragraph, it is found that the surface temperature and HIP temperature differ from the shadow of apartment house building, indoor cooling temperature set and the materials of ground surface paving.

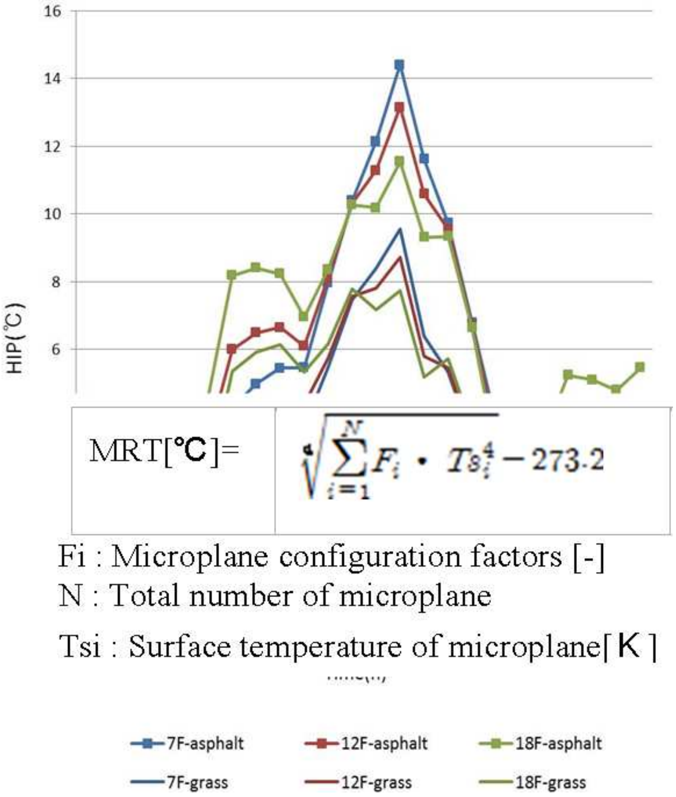
Figure 8 is the surface temperature profile of 18F according to the materials of ground surface paving and ecological planting method, based on such result. In all scenarios, the shadow area of building show low surface temperature.

In respect of paving material, grass showed 5□7℃ lower temperature profile than asphalt but little difference when grass and rooftop planting were applied together. When rooftop planting was applied, temperature reduction was effective in more than 10□15℃, in every time period. Such result makes rooftop planting become a good consideration for the indoor cooling/heating method of building.

4.3.2 MRT distribution

MRT is the averaged and conversed temperature of the effect of heat radiation that is felt in all directions by human. Figure 9 is the result of MRT distribution calculated at 1.5m height of site area in each time period.

MRT(Mean Radiant Temperature) indicates the average temperature of all directions, considering the effect of heat radiation applied to buildings and outer space.



$$MRT[℃]=\sqrt[4]{\sum_{i=1}^{N} F_i \cdot Ts_i^4}-273.2$$

Fi : Microplane configuration factors [-]

N : Total number of microplane

Tsi : Surface temperature of microplane[K]

Figure 7: HIP Distribution of asphalt and grass

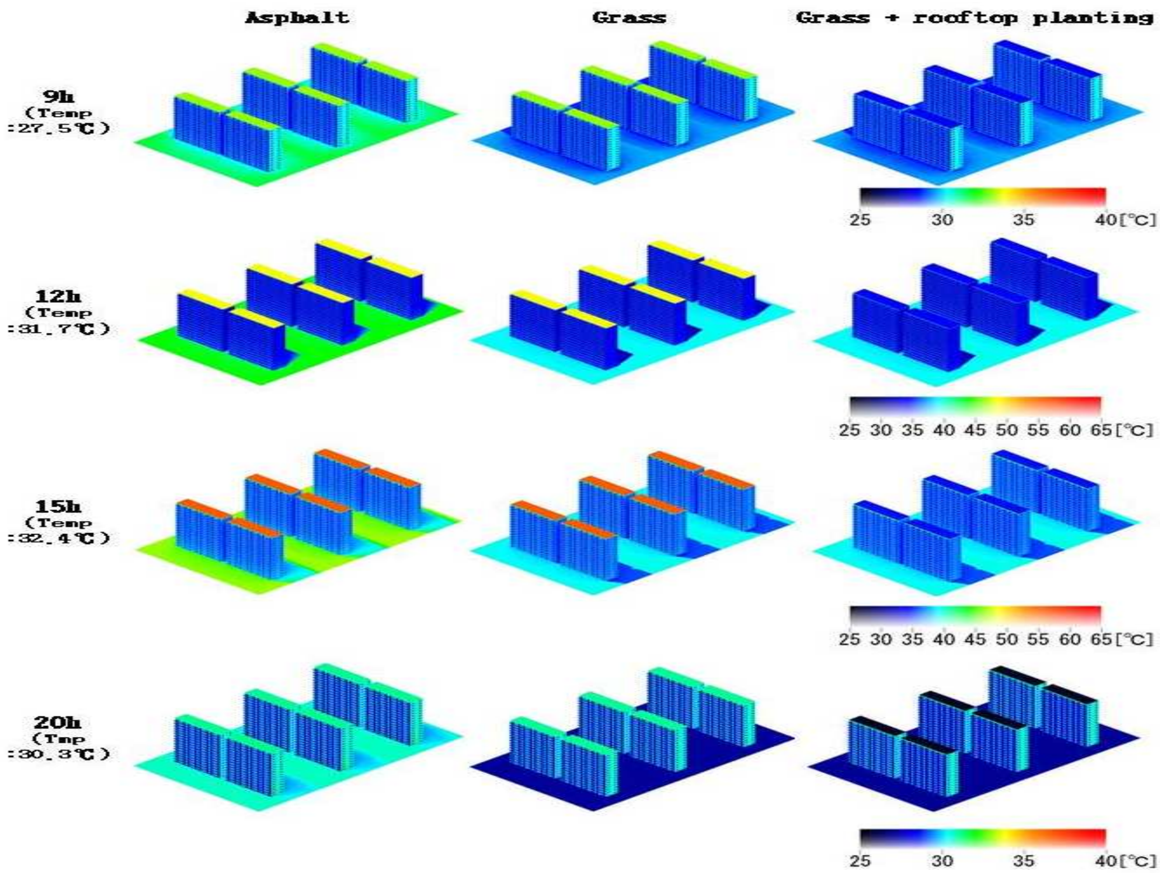


Figure 8: Surface temperature of according to the materials of ground surface paving

In respect of paving materials, asphalt was 33.4℃ and grass was 31.6℃ at AM 12, showing 1.8℃ difference. In other time periods, they showed about 0.5℃ ~ 1.4℃ difference, indicating that radiation heat is bigger in asphalt. It was found that building and asphalt around building have higher MRT than grass. It can be said that artificial structures influence on the comfort of living space through the radiation heat generated from buildings.

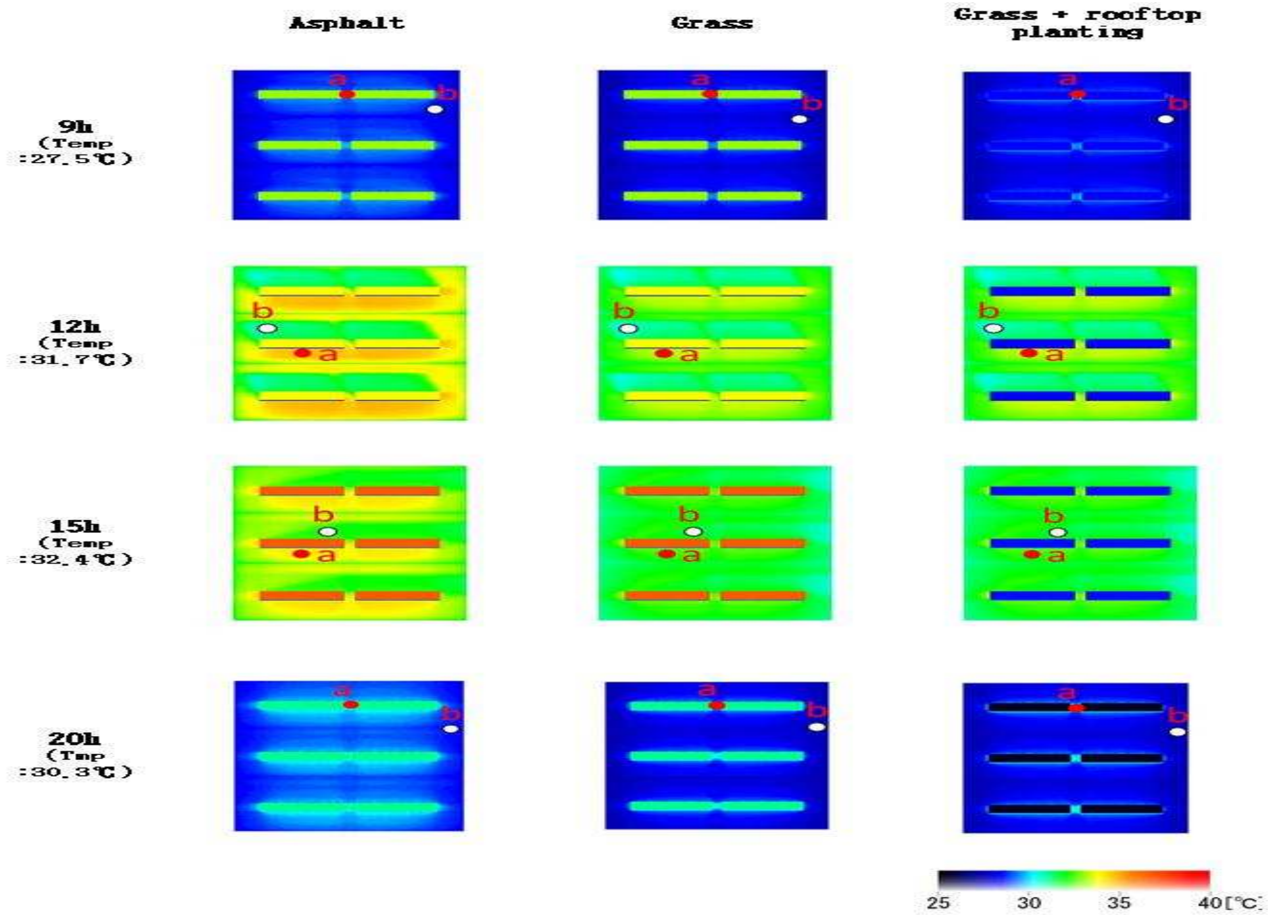


Figure 9: MRT distribution of according to the materials of ground surface paving

4.3.3 HIP distribution

Figure 10, HIP result according to ecological planting, shows the highest HIP of 11.45℃by asphalt at 1PM. Grass was highest by 7.78℃ and grass & rooftop planting was highest by 6.45℃ at 11 AM. Asphalt and grass of ecological planting showed about 4~5℃ difference with grass & rooftop planting.

Comparing grass paving and grass & rooftop planting, rooftop planting showed relatively stronger effect at every time period. It can be said that such result was caused by the function of sensible heat depression effect, such as heat insulation of land by rooftop planting or heat reduction from evaporation.

ISBN: 978-3-9503110-0-6 (CD-ROM); ISBN: 978-3-9503110-1-3 (Print) **Editors: Manfred SCHRENK, Vasily V. POPOVICH, Peter ZEILE**

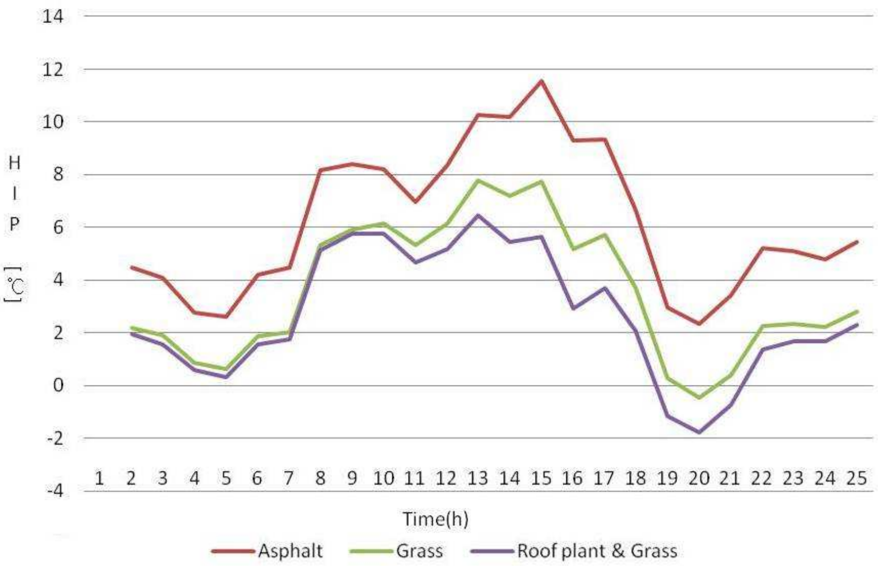


Figure 10: HIP distribution of ecological planting

5 CONCLUSION

This analysis used Thermo Render, the 3D heat environment simulation model on the basis of the relationship between land cover, structure and urban heat environment, in order to quantitatively evaluate the heat environment of apartment complex according to the floor number deregulation of the apartment houses.

For the temperature distribution of the ground surface based on the floor number deregulation of the apartment houses, there was a temperature difference between depending on the quality of the earth's surface, however all surface temperatures declined equally due to the shadow at each floor according to the quality. Besides, the taller the building is, the higher the ratio of shadow area in the complex appears, and especially the surface temperature difference from the sunny spot is shown to be significantly large during the daytime.

From MRT distribution result, it was found that the radiation heat had the most effect on asphalt. It can be said that artificial structures influence on the comfort of living space through the radiation heat generated from buildings.

HIP results have a similar tendency in every floor. Higher floors showed lower temperature than lower floors maybe because wider shadow area formed on ground surface could keep that area at lower temperature and also low HIP. In addition, the fact the indoor temperature set at 26℃ kept the surface temperature around veranda low could be another cause.

In the result from ecological planting method, it was found that asphalt & grass and grass & rooftop planting were applied together, there were about 4~5℃of temperature distribution. Therefore, ecological planting method should be considered in future apartment house development.

6 ACKNOWLEDGEMENTT

This work (2010-0026738) was supported by Mid- career Researcher Program through NRF grant funded by the MEST

7 REFERENCES

Park, Eun-Tae. Kang, Byoung-eun: A Research on Analysis of Sunlight Environment Impact of Certfied Green Building Apartment Complex. . Journal of the Architecture Institute of Korea, Vol. 23, Issue 9, pp.3-13. Seoul, 2007.

Oh, Kyushik, Seo, Anseon. Jung Seunghyun: Planning Apartment Complex to Enhance Thermal Environment. Journal of the Korean Environment Research Technology, Vol. 12, Issue2, pp. 83-94. Seoul, 2009.

Yoon, Seong-Hwan. Jeong, Seon-Yeong: Predictive Evaluation of Outdoor Thermal Environment in Summer of Apartment Housing According to Building Types and Site Planning Types. Journal of the Architecture Institute of Korea, Vol. 25, Issue9, pp. 321-328. Seoul. 2009.

Yoon, Seong-Hwan. Jeong, Seon-Yeong: Evaluation of Outdoor Thermal Envionment in Summer OF Flat-type Apartment Houses and Tower-type Apartment Houses Using Numerical Simulation of All-Surface-temperature of 3-Dimension. Journal of the Architecture Institute of Korea, Vol24, Issue10, pp. 259-266. Seoul. 2008.

Jeon, Mi-Young. Lee, Seung-Jae. Kim, Ji-Yoeng. Leigh, Seung-Bok. Kim, Tae-Yeon: Evaluation of the Thermal Environment and Comfort in Apartment complex using Unsteady-state CFD simulation. Journal of the Korean Institute Ecological Architecture and Environment, Vol. 10, Issue4, pp. 67-73. Seoul, 2010

Shinji YAMAMURA, Akira HOYANO, Tkashi ASAWA: A Study on Prediction Method of Thermal Radiant Environment in Outdoor Space for the Computer aided design tool. J. Archit. Plann. Environ., AIJ, Vol. 554, pp. 85-92. Tokyo. 2002

Akira HOYANO, Tkashi ASAWA, Akinobu MURAKAMI, Rihito SATA, Kzauaki NAKAOHKUBO. 3D-CAD Modelling of a Substantial Urban area and Heat Island Potential of Urban Blocks in Summer. J. Archit. Plann. Environ., AIJ, Vol. 312, pp. 97-104. Tokyo. 2007